Aerosol Direct Radiative Effect During Covid-19

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Aerosol Direct Radiative Effect

$$ADRE = F(0, \alpha; x_1, x_2, \ldots, x_n) - F(\tau_a, \alpha; x_1, x_2, \ldots, x_n)$$

$F(0, \alpha; x_1, x_2, \ldots, x_n)$ = Clear-sky SW TOA Flux with no aerosol

$F(\tau_a, \alpha; x_1, x_2, \ldots, x_n)$ = Clear-sky SW TOA Flux with aerosol

Aerosol Direct Radiative Effect Anomaly

$$\delta ADRE = \delta F(0, \alpha) - \delta F(\tau_a, \alpha)$$

$\delta F(\tau_a, \alpha)$ can be decomposed into atmospheric and surface contributions using EBAF TOA and surface radiative fluxes:

$$\delta F(\tau_a, \alpha) = \delta F(ATM) + \delta F(SFC)$$

- First term on RHS accounts for atmospheric variations for a fixed climatological surface albedo.
- Second term on RHS accounts for surface albedo variations, determined from difference between the other two terms.

Aerosol Direct Radiative Effect Anomaly

$$\delta ADRE = -\delta F(ATM) + [\delta F(0,\alpha) - \delta F(SFC)]$$

Atmosphere-Only Variations

Masking effect of aerosols on surface albedo variations simply due to the presence of aerosols

$-\delta F(ATM)$ Determined from EBAF Ed4.1 product.

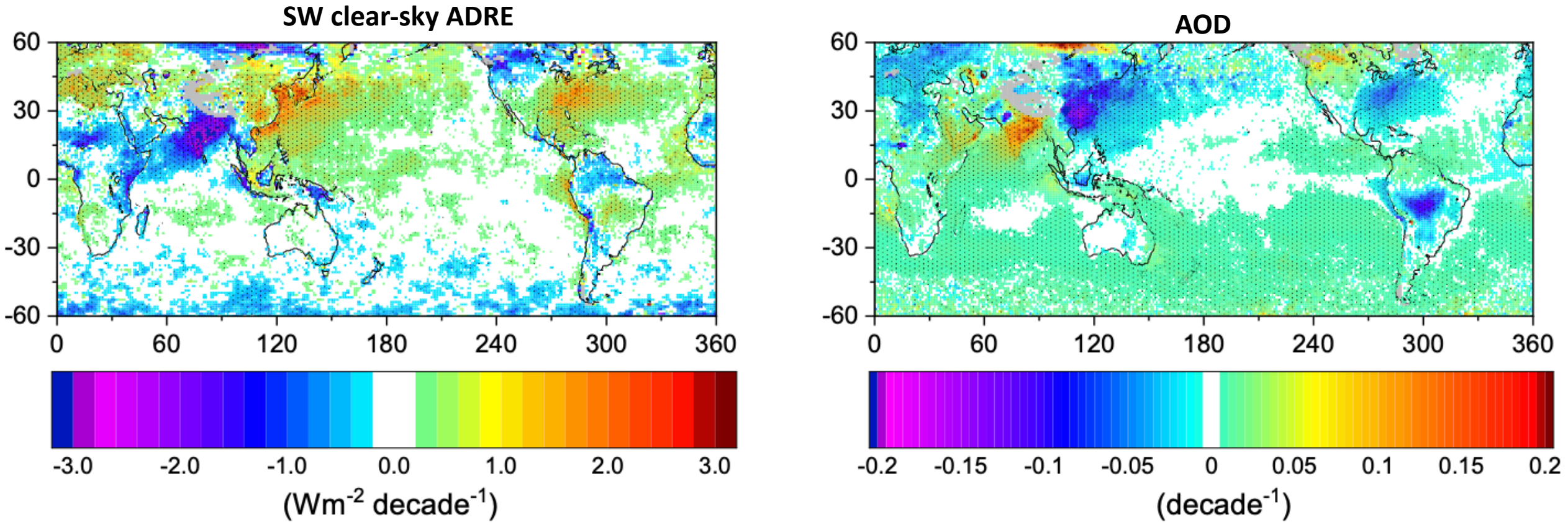
$[\delta F(0,\alpha) - \delta F(SFC)]$ Determined from SYN1deg product.

Observations

- CERES EBAF Ed4.1
- CERES SSF1deg-Aqua Ed4.0
- CERES SYN1deg-Terra_Aqua Ed4.0
- Nino 3.4 Index from NOAA ESRL
- MODIS MYD08_M3.061 550 nm AOD Dark Target+Deep Blue Combined
- MERRA-2 U2M, V2M, T2M, QV2M

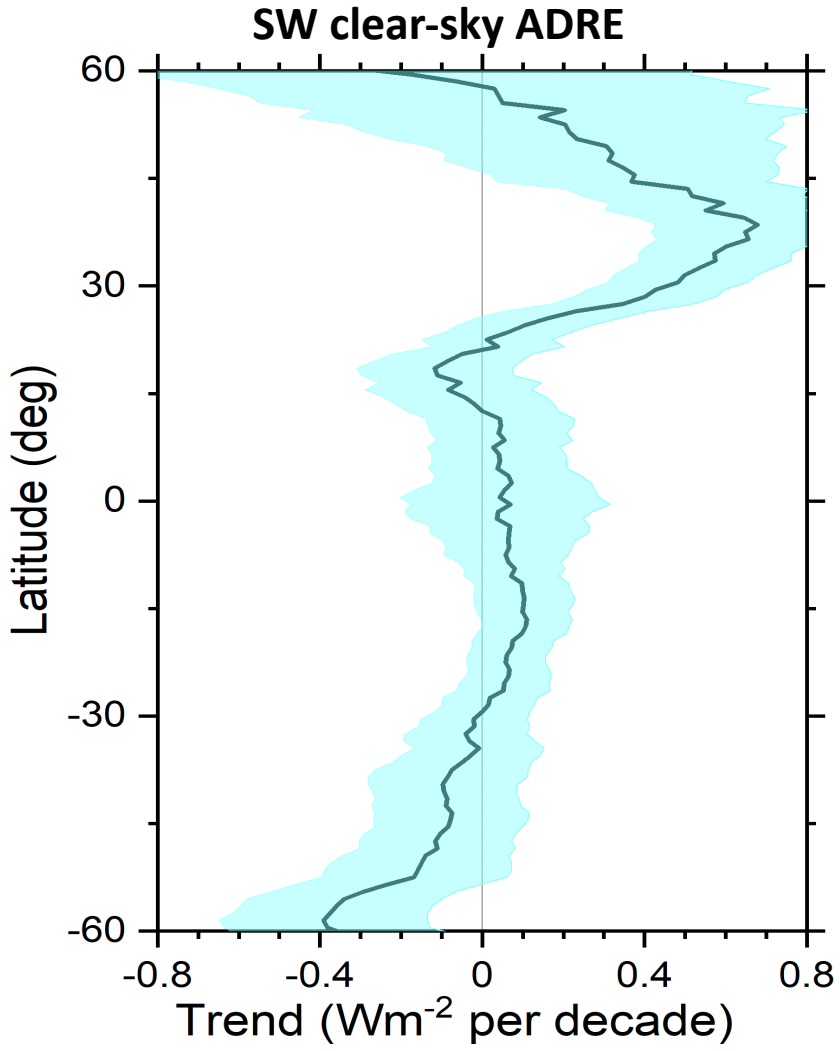
Dates: 07/2002-03/2020
Surface Types: ocean, land and desert (no snow/sea-ice).

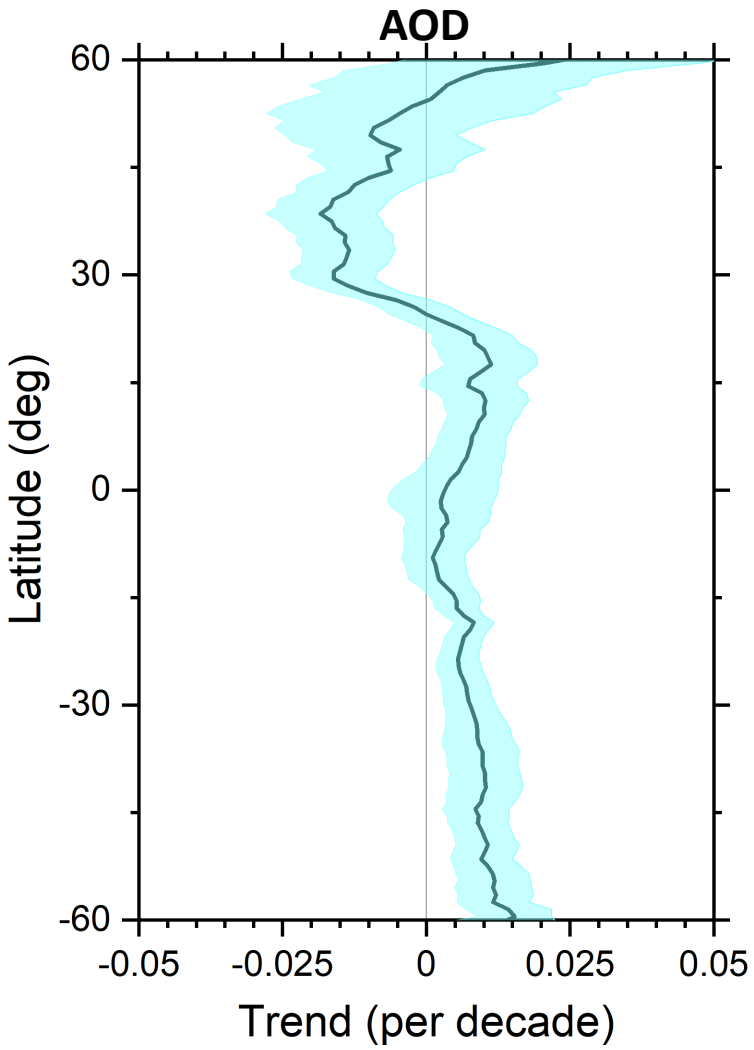
Trend in Regional Anomalies of SW Clear-Sky ADRE and AOD (2002/07-2020/03)



- Stippled area exceeds 95% confidence interval in trend.
- Significant increase in ADRE and decrease in AOD over China and east coast of North America. Decrease in ADRE and increase in AOD over India.
- AOD shows widespread significant increase over Ocean in Southern Hemisphere. Inconsistent with ADRE trend.

Trend in Zonal Mean Anomalies of SW Clear-Sky ADRE and AOD (2002/07-2020/03)

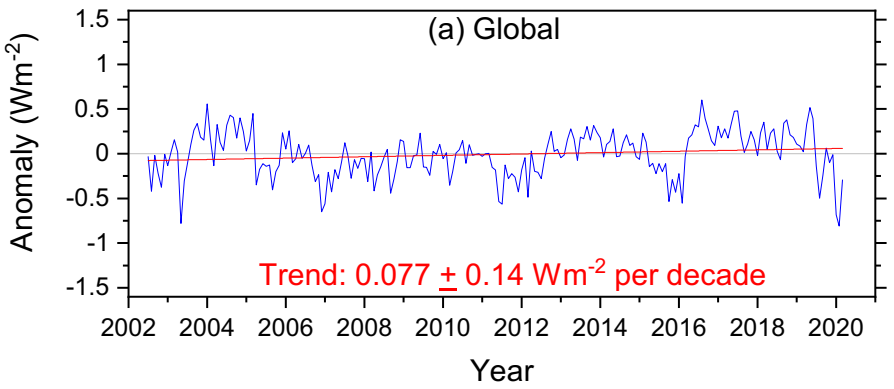


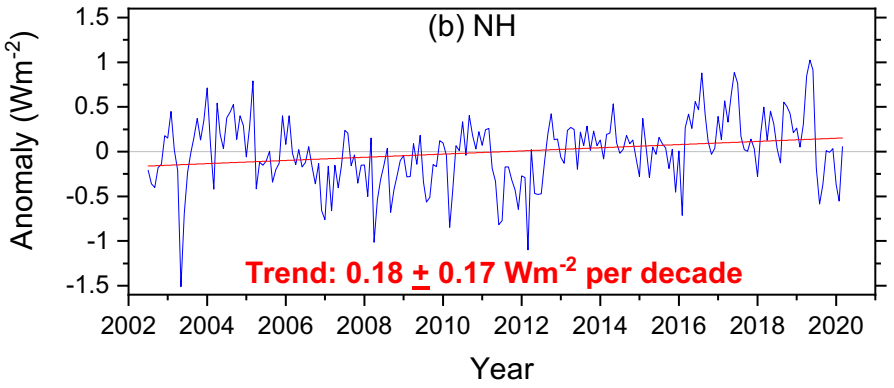


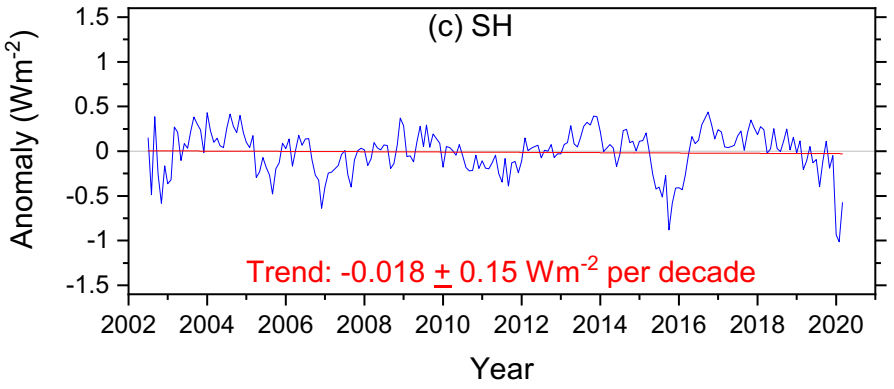
- Shaded regions correspond to 95% confidence interval.

Anomalies in ADRE and AOD for Global, Northern and Southern Hemispheres (07/2002—03/2020)

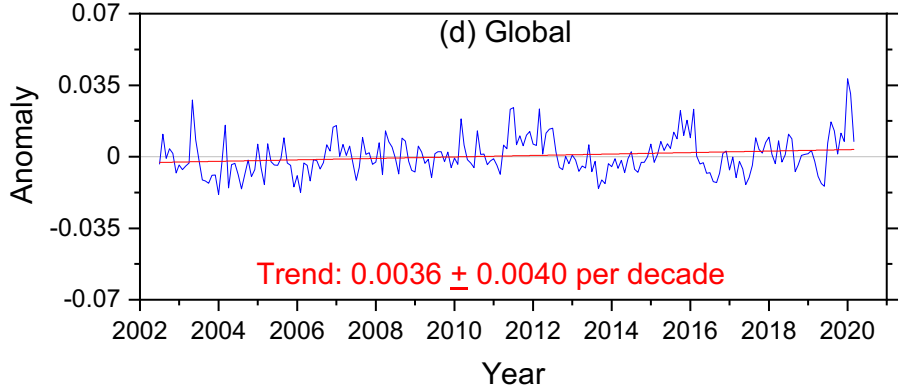
ADRE

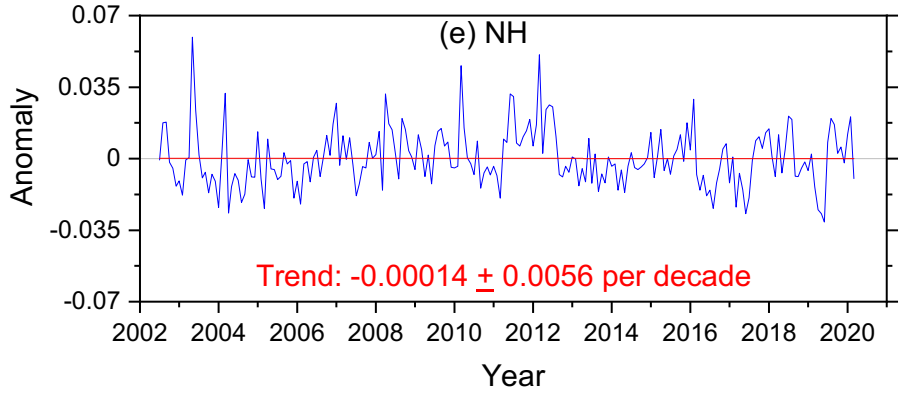


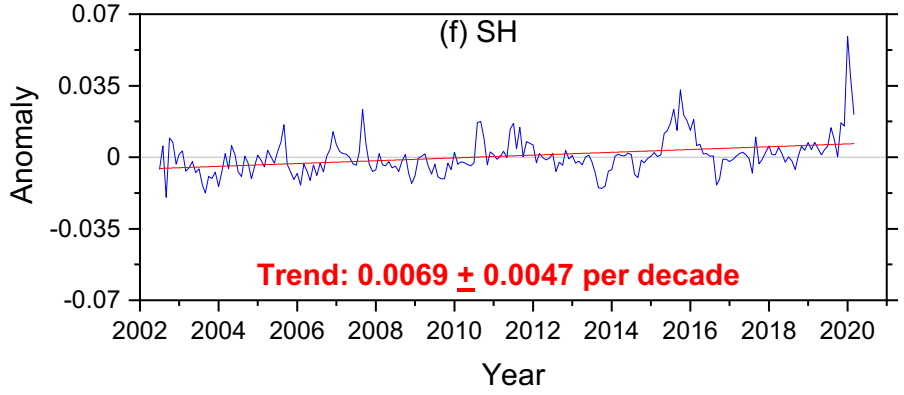




AOD





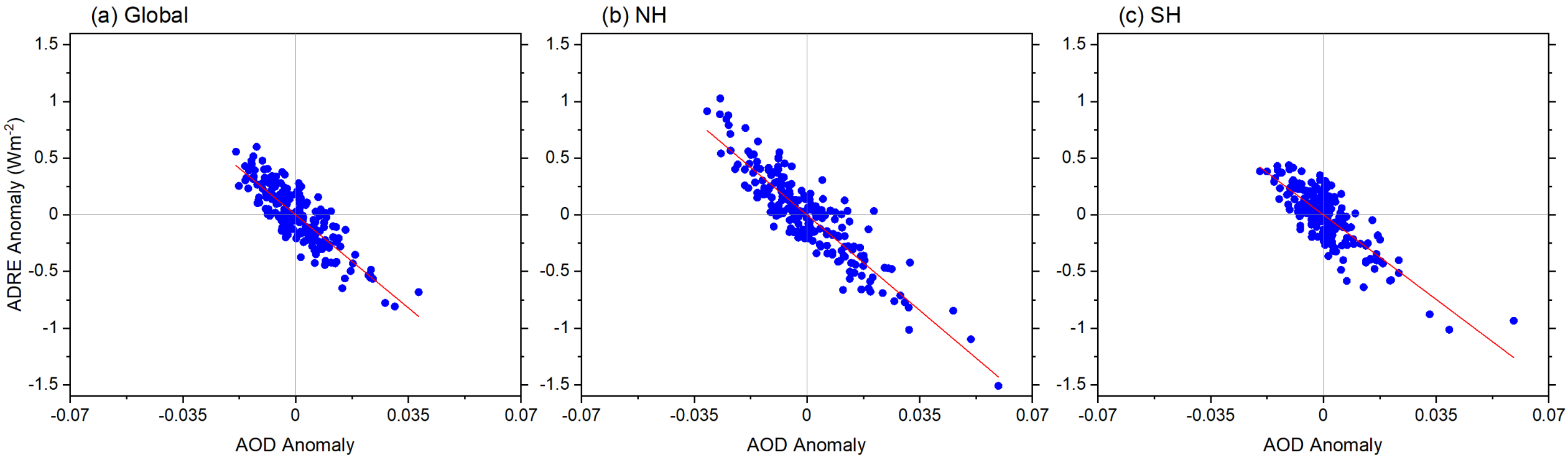


- No significant global trends

- ADRE: +ve trend in NH

- Surprising SH trend in AOD.
- Possible calibration drift in MODIS?

Scatterplots of ADRE vs AOD Anomalies



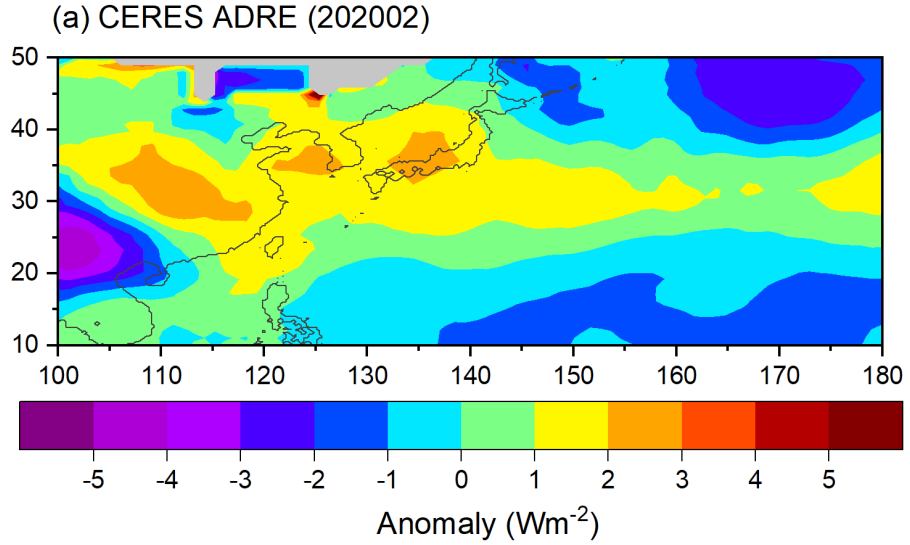
Slope: –23.5 ± 1.0 Wm^{-2} per τ
R^2: 0.71

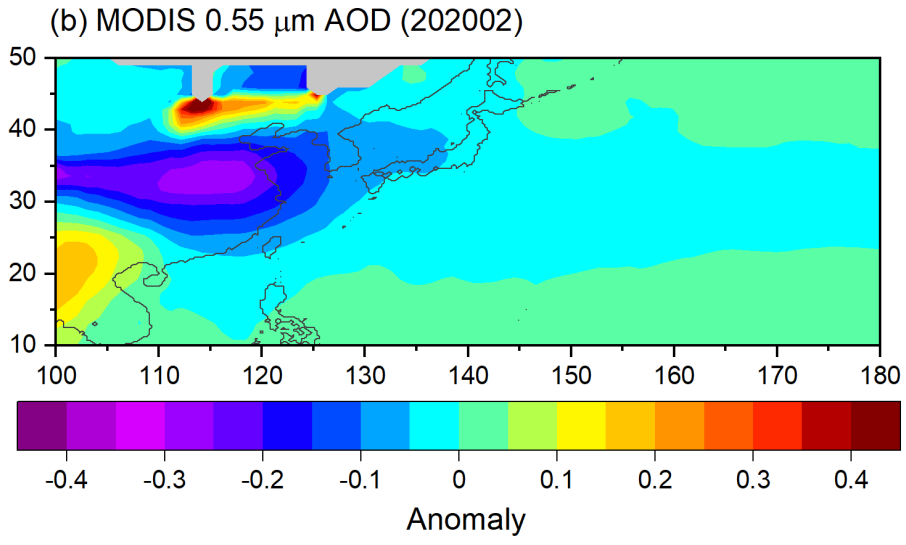
Slope: –24.1 ± 0.81 Wm^{-2} per τ
R^2: 0.81

Slope: –21.3 ± 1.1 Wm^{-2} per τ
R^2: 0.65

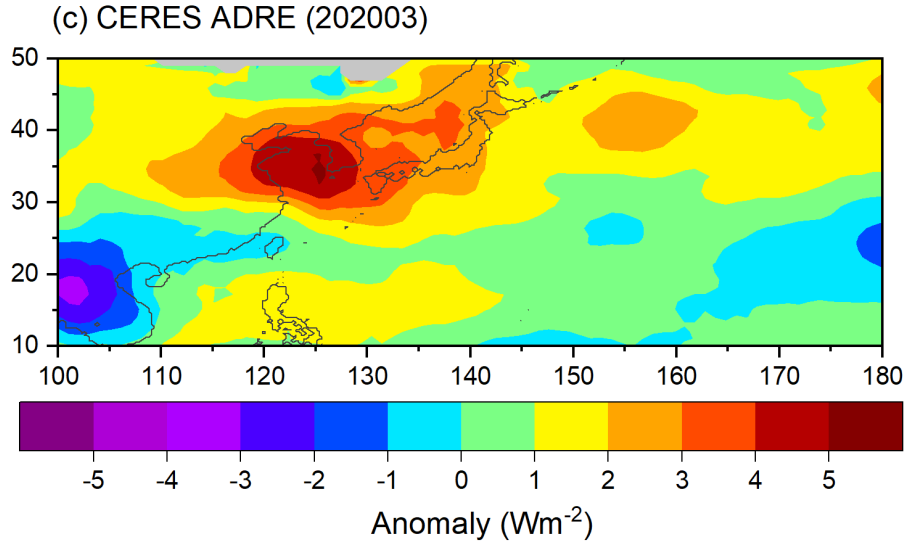
Anomalies of ADRE and AOD for February 2020 and March 2020 Over China

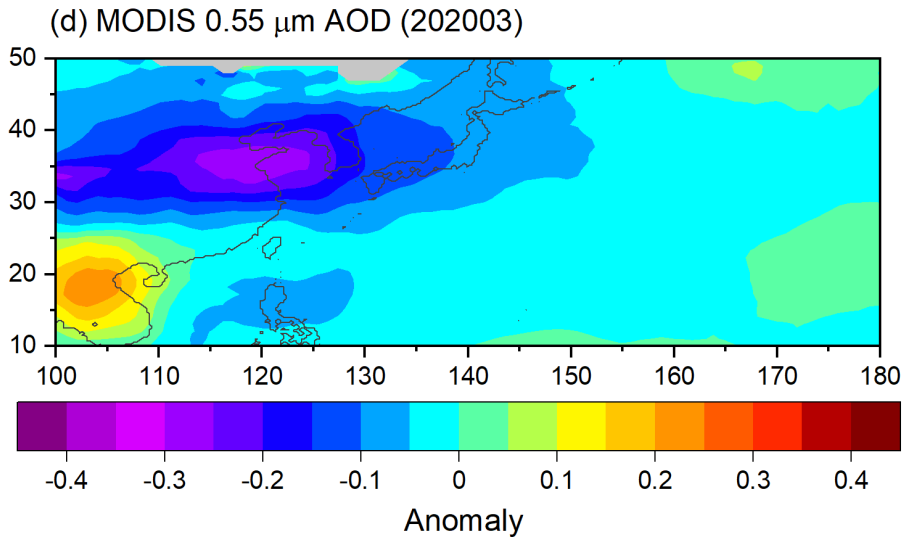
February 2020





March 2020





- Transportation and industrial activity during Covid-19 shutdown in China was at a minimum in February, yet ADRE anomalies over eastern China are much greater in March than February. Why?
- In contrast, AOD anomalies are similar in February and March. Why?

Accounting for Regional Meteorological Variability

- Use multilinear regression model to relate anomalies in ADRE and AOD with anomalies in:

  i) Niño 3.4 index (NOAA ESRL)

  ii) 2-meter eastward wind (U2M) (MERRA-2)

  iii) 2-meter northward wind (V2M) (MERRA-2)

  iv) Estimated Inversion Strength (EIS) (CERES SSF1deg)

  v) 2-m air temperature (T2M) (MERRA-2)

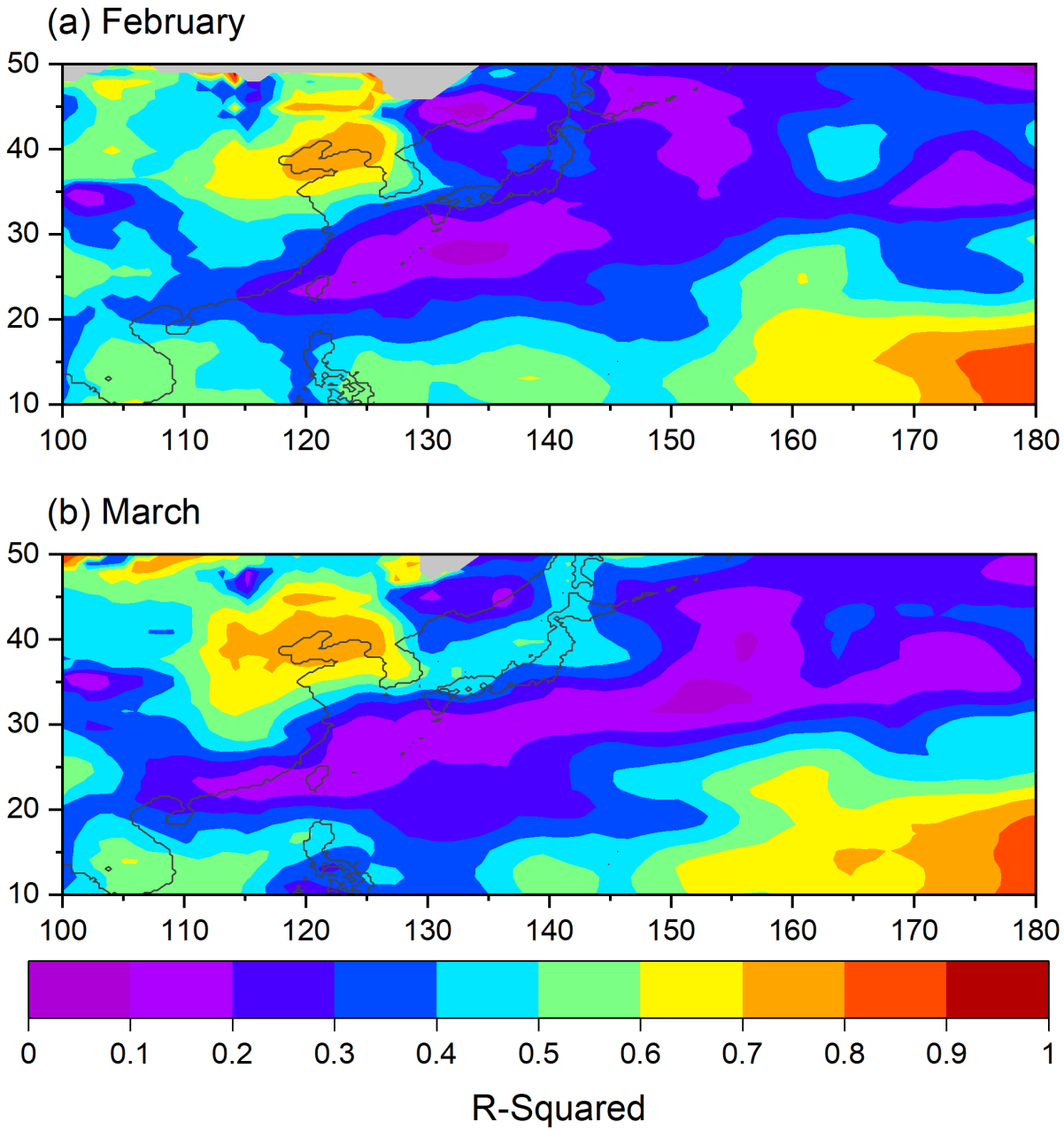
  vi) 2-m specific humidity (QV2M) (MERRA-2)

  vii) Daytime average cloud fraction between the surface and 700 mb (CERES SSF1deg)

<u>Notes:</u>

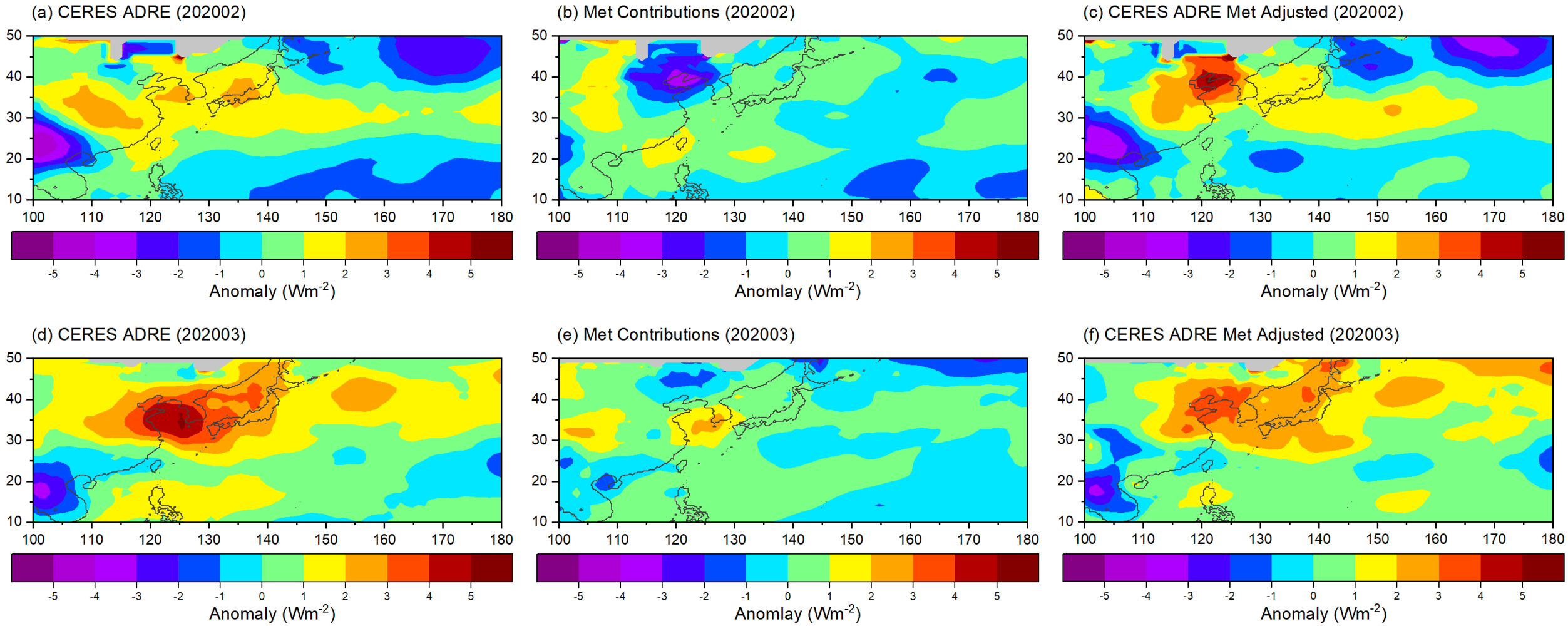
- All variables are detrended prior to determining multilinear regression fit
- Derive multilinear regression fit for 9°×9° latitude-longitude moving window (steps of 1°)

R-Squared values for multilinear regression fits to ADRE monthly anomalies (2003-2020)

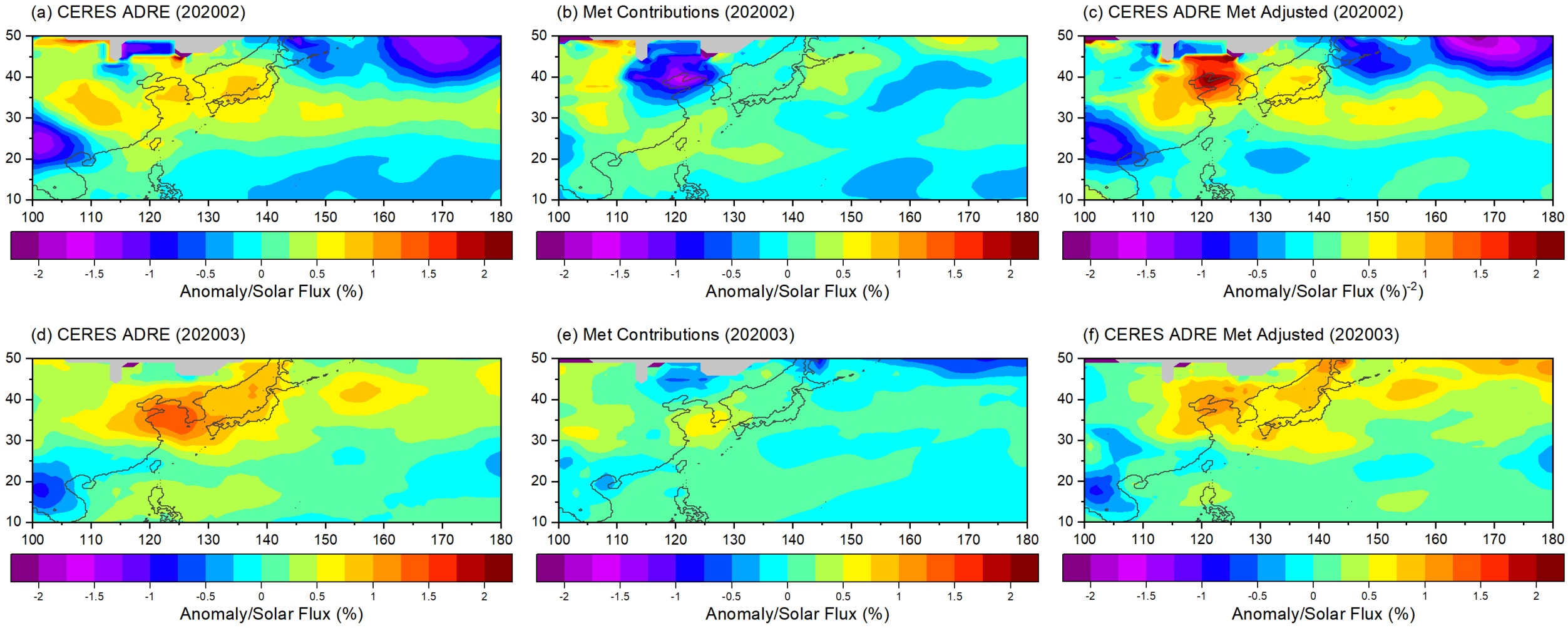


- Explained variance (R^2) reaches 0.8 over Yellow Sea region.
- Low R^2 values over ocean away from coast.

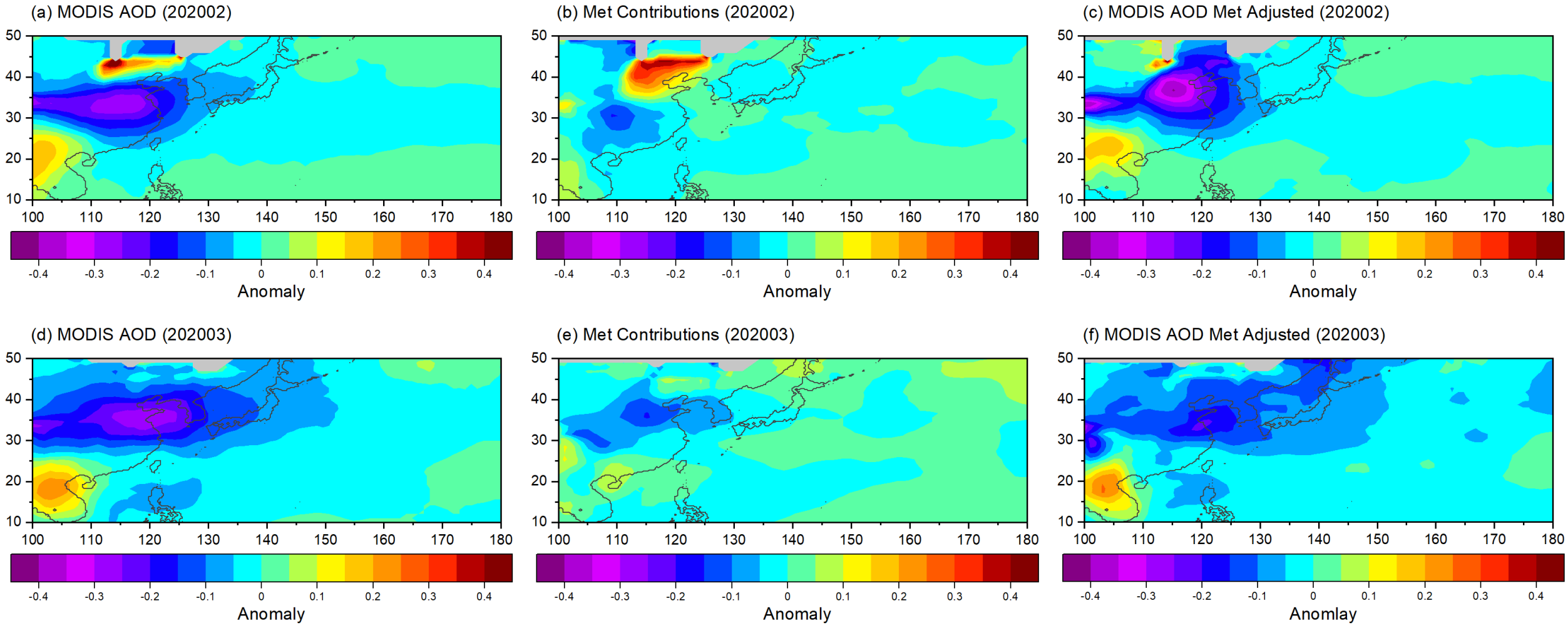
ADRE Anomalies for February & March 2020: Accounting for Meteorology



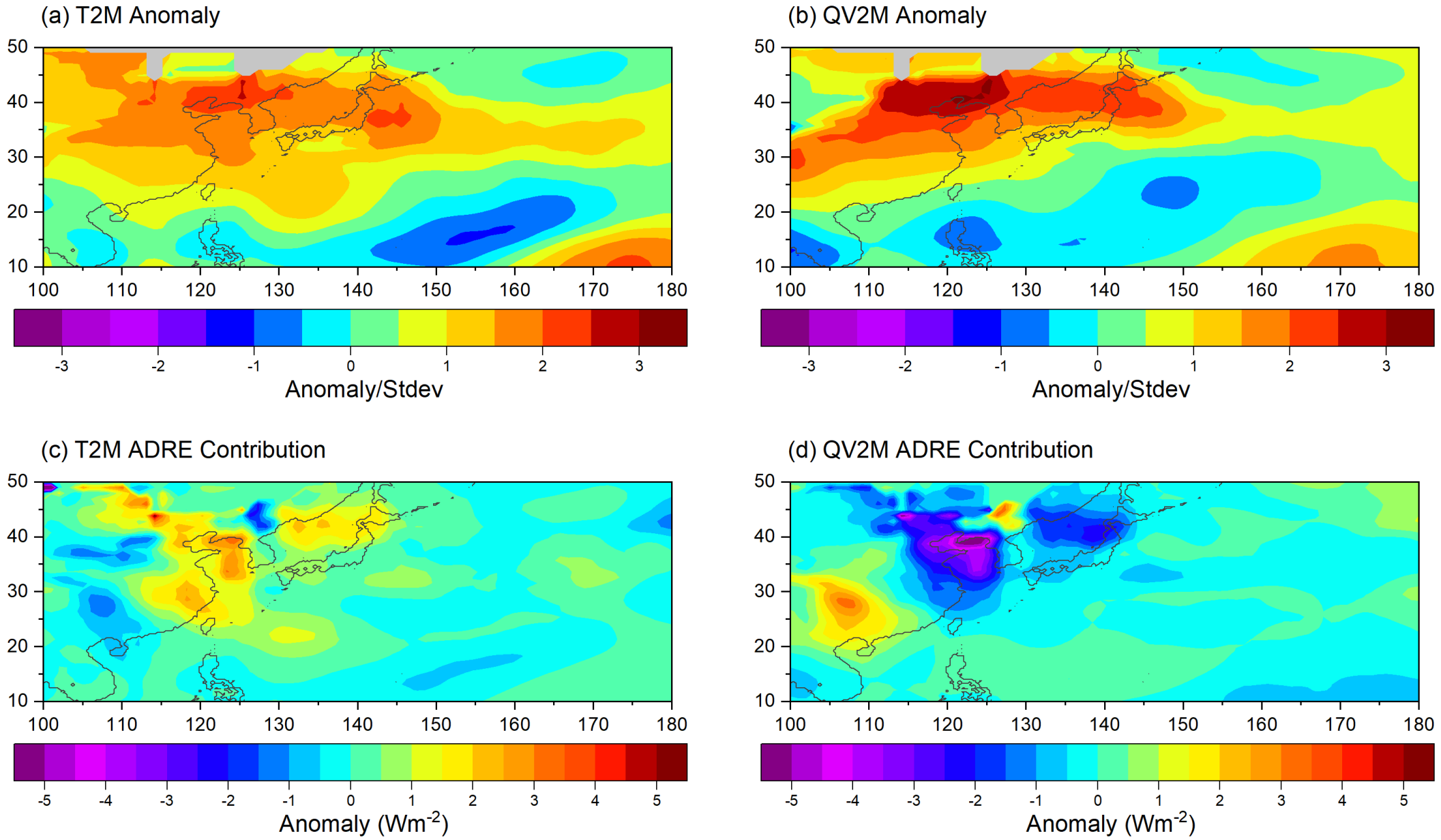
ADRE Anomalies for Feb & Mar 2020: Accounting for Meteorology & Incoming Solar Flux



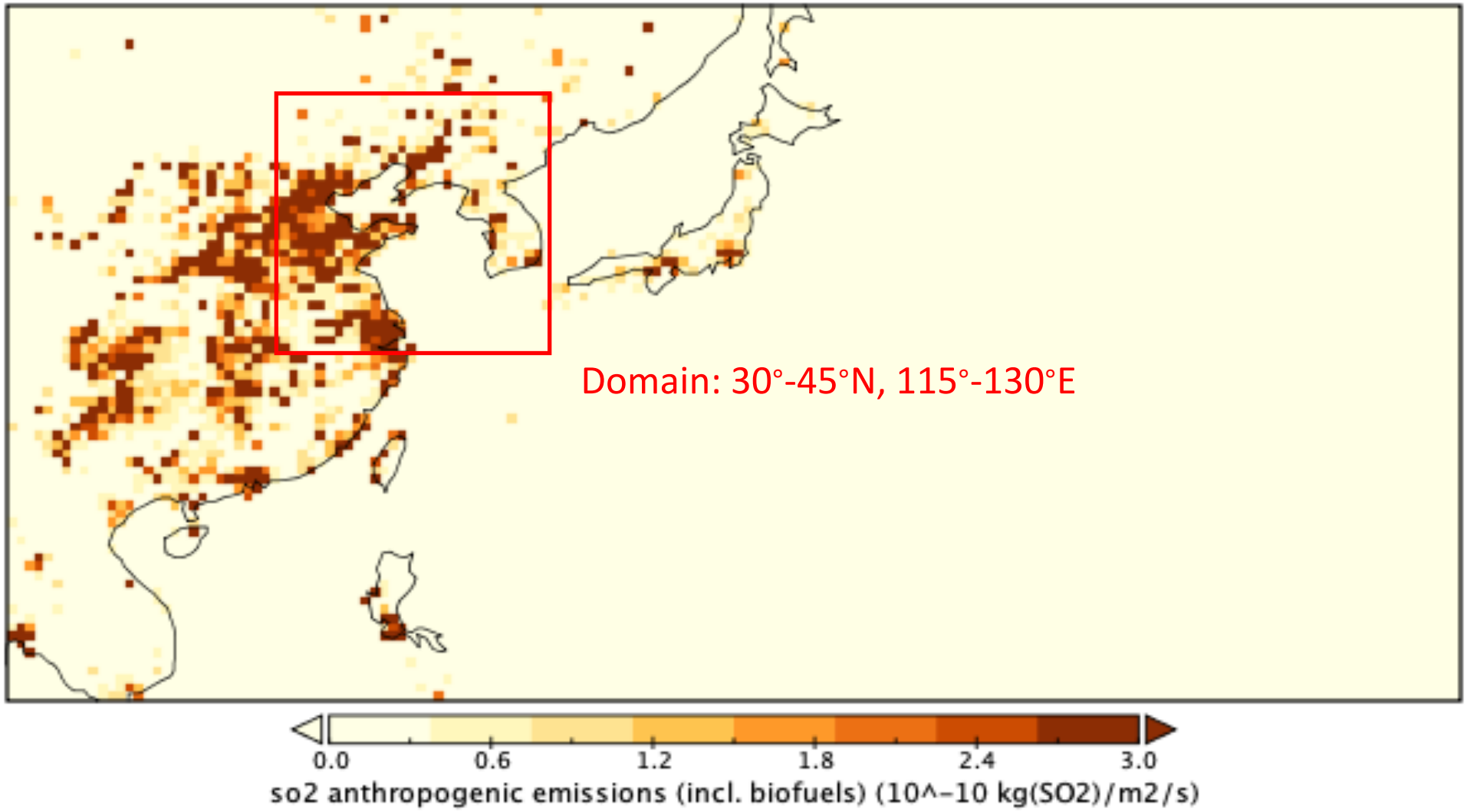
AOD Anomalies for Feb & Mar 2020: Accounting for Meteorology



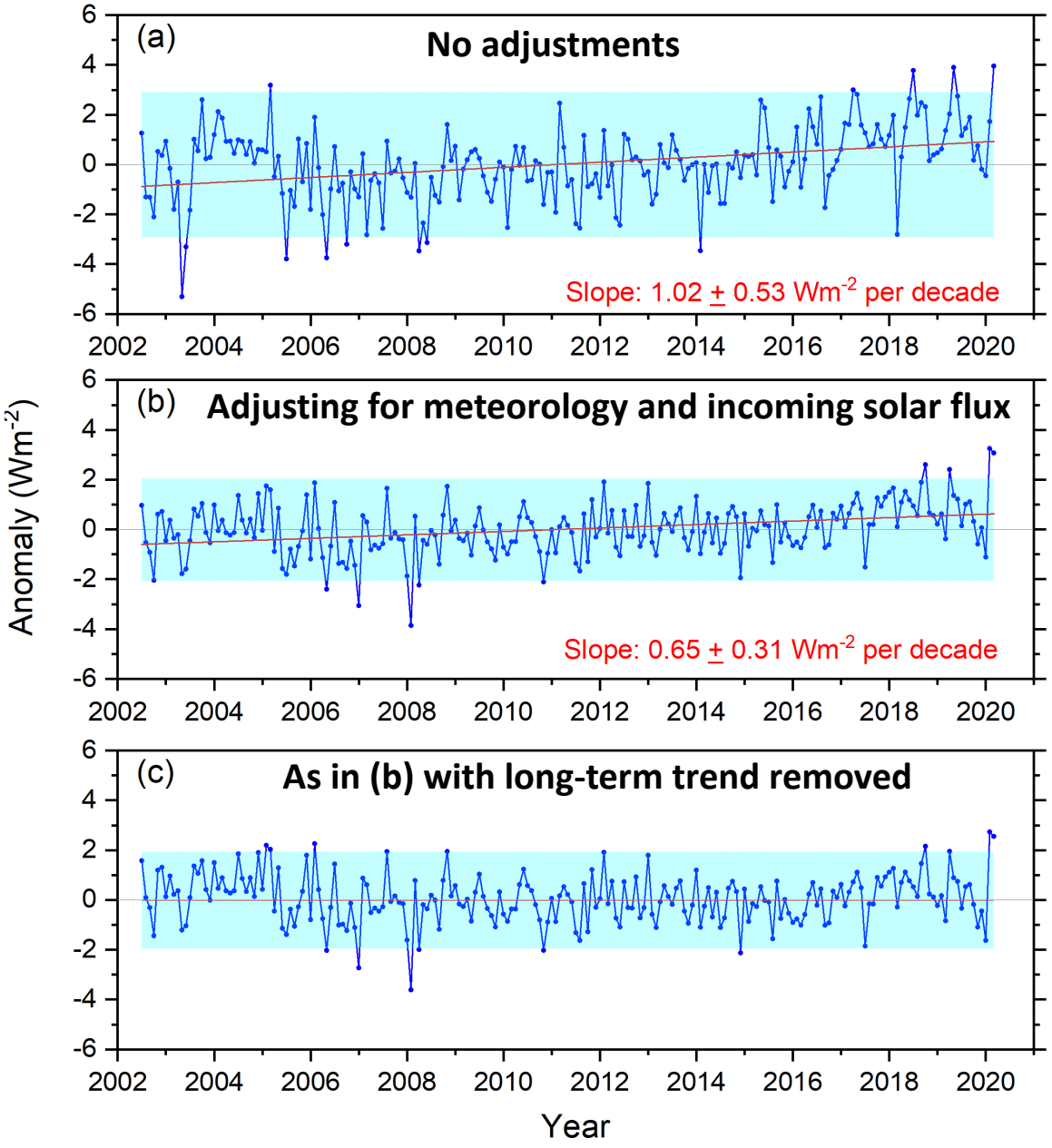
Anomalies in T2M and QV2M and Contributions to ADRE Anomalies (February 2020)



Anthropogenic Emissions of SO_2 (including biofuels) for March 2005



Monthly Anomalies in ADRE over China (30°-45°N, 115°-130°E)



- Positive ADRE long-term trend due mainly to pollution controls
- Corresponds to 1.8 Wm^{-2} over 17.7 years (13% increase in ADRE relative to the climatological average)

- Accounting for meteorology and solar flux reduces both long-term trend and variability.

- After accounting for meteorology, solar flux and removing long-term trend:

⇒ Feb & Mar 2020 are only two consecutive months whose anomalies exceed 95% confidence interval.

⇒ ADRE values for Feb and Mar 2020 are 17% larger than the corresponding ADRE climatological averages

Conclusions (1/2)

- We have introduced a new method for determining anomalies in ADRE from CERES EBAF Ed4.1 and SYN1deg data.
  - Monthly anomalies in ADRE are consistent with MODIS AOD anomalies (R^2=0.8 for NH).
  - Pattern of regional ADRE trends resemble those for MODIS AOD, except over SH oceans.
  - Significant ADRE trend in NH due to pollution controls in China and USA.
  - No significant global trend in ADRE or AOD.

Conclusions (2/2)

- Meteorology played a significant role in explaining the lack of a strong signal in ADRE and AOD in February 2020, when the economic activity in China was at its minimum.
  - ADRE anomalies in March 2020 exceeded those in February 2020 over eastern China.
  - When adjusting for meteorology and incoming solar flux, anomalies in February dramatically increase.
  - T2M and QV2M are the largest contributors to ADRE in Feb 2020.
  - After accounting for meteorology and solar flux, February and March 2020 are the only two consecutive months in the CERES record to exceed the 95% significance level, even after long-term trend is removed.

  => Anomalous meteorological conditions masked the full impact of the Covid-19 shutdown on clear-sky SW TOA radiation over eastern China.